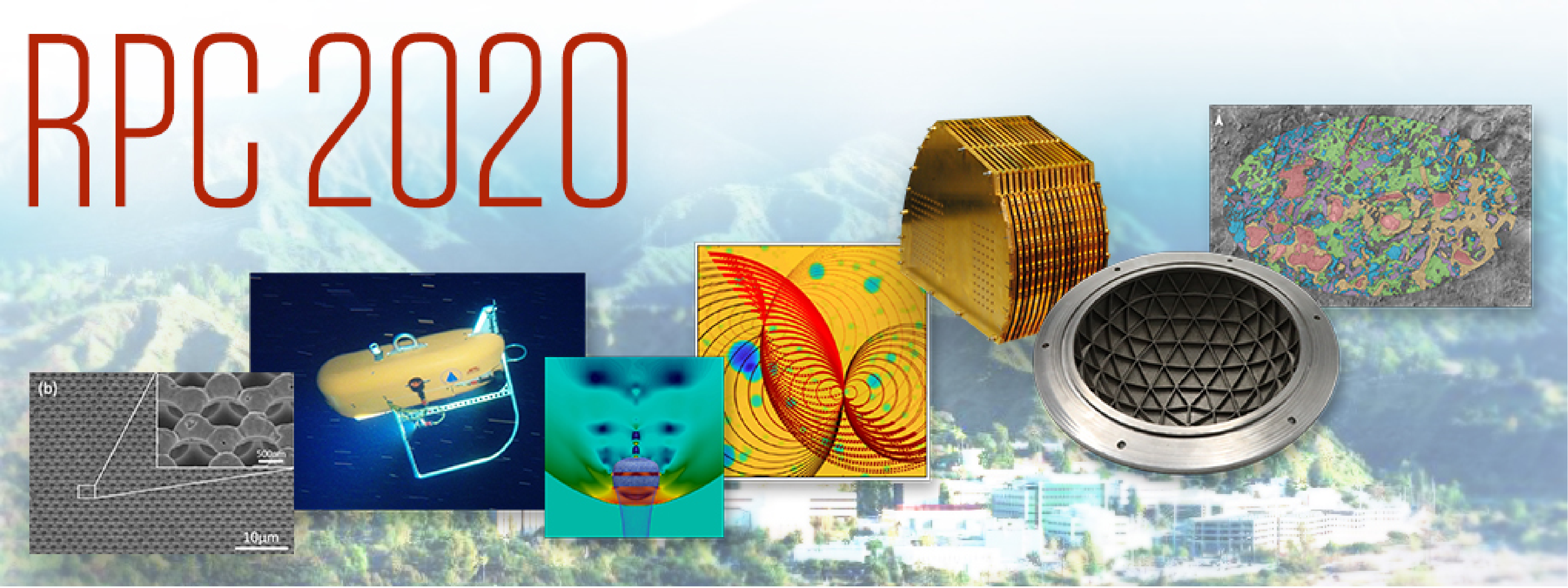

Virtual Research Presentation Conference

Assessment of Terrain Trafficability using the M2020 Abrading Bit

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Program: Topic

RPC-263

Jet Propulsion Laboratory
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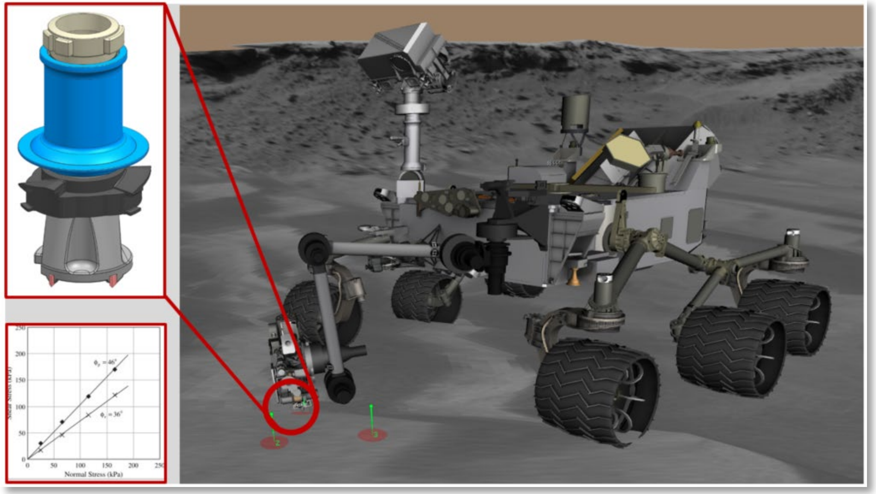
Tutorial Introduction

Abstract

NASA's Curiosity and MER rovers have each traversed myriad "sandy" regions, which are both pervasive across Mars' surface and a certainty to be encountered by future missions. On such terrains, rover performance is limited not by wheel torques but by the strength of the material and its ability to support locomotion. Accurate predictions of mobility performance have been, and presently remain, infeasible and the requisite terrain-strength properties are yet to be measured. This precipitates the use of anecdotal evidence and after-the-fact curve-fitting as the state of the art. This study aims to demonstrate that predictive models of rover mobility performance can be greatly informed by terrain strength measurements obtained using the Mars 2020 Abrading Bit, a tool of similar form and function to that of a Bevameter. The results of this study, if transferred into flight, are capable of improving Mars 2020 operations, the design of downstream surface mobility systems, and the generation of accurate Mars regolith analogues.

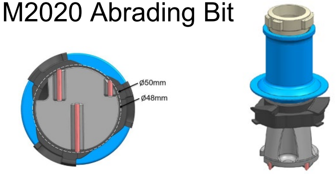


Problem Description

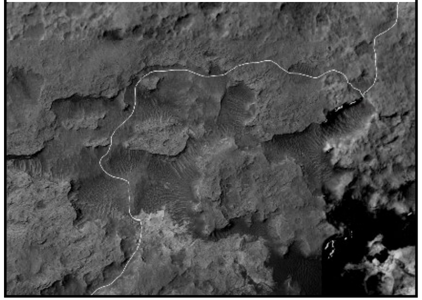
a) Context (Why this problem and why now)

The design of the Mars 2020 abrading bit is analogous to that of a Bevameter - a soil geotechnical instrument needed to describe and model vehicle-terrain mechanics - to the extent that no changes to hardware or software designs are necessary. This is both fortuitous and an opportunity to enable a new capability on Mars. Altering the manner in which the abrading bit is used in flight may be sequenced by Rover Planners, the feasibility of which has recently been shown during recovery from the Curiosity drill feed anomaly. As such, the path to flight infusion may be achieved at an unusually low cost to high return ratio.

M2020 Abrading Bit



MSL: Avoidance of sand:
Shortest route = 380 m.
Actual distance driven = 604 m



b) SOA (Comparison or advancement over current state-of-the-art)

An instrument to measure the strength and spatial variation of Mars' regolith has never flown; as primarily an engineering instrument, such a device would consume mass and volume otherwise available for science payloads. This has precipitated the use of anecdotal evidence and posteriori curve-fitting as the state of the art, which lacks predictive capability and is generally very low fidelity compared to terrestrial SOA. Curiosity, Opportunity, and Spirit have each been placed at significant risk of immobilization on sand (Spirit's entrapment, Opportunity at Purgatory, and Curiosity at Hidden Valley) and are testament to the insufficiency of such methods. The failure of the InSight lander's mole instrument is another, more recent, example of why designing around mechanism-terrain interactions is important.

Problem Description

c) Relevance to NASA and JPL (Impact on current or future programs)

The results of this study, if transferred into flight, hold promise in three areas:

1. In situ measurements of terrain strength can lead to greater operational understanding of traversability risk
2. Provide geotechnical characterization of the strength of loose material in Jezero Crater, which may be used to inform the development of the MSR Sample Fetch rover, and Mars Human Landing Systems (JEZ is a potential HLS program landing site as well)
3. **JPL may be able to produce the first systematically developed Mars, in situ measurement informed, regolith analogue for mobility, sampling, and ISRU applications**

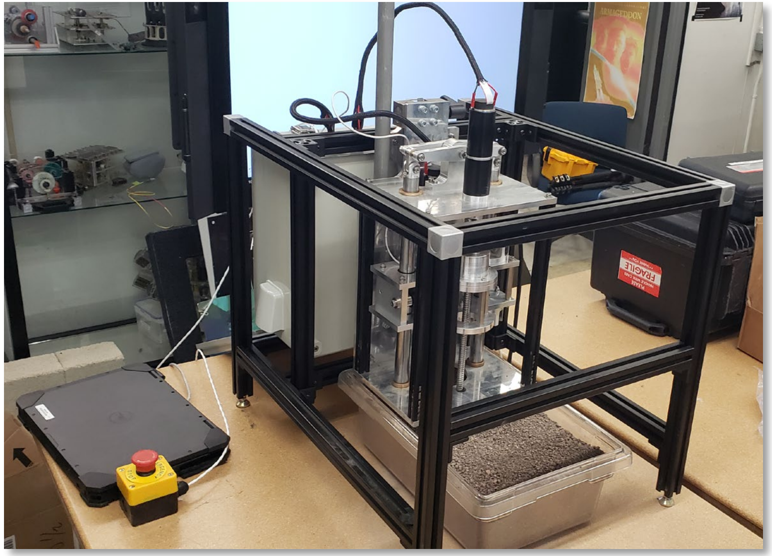
Terrain mechanics: NATO, TARDEC, Army, Industry, GRC, industry. Important result of Apollo: JSC-1, GRC-1

Methodology

a) Formulation, theory or experiment description

- Abrading bit geotechnical measurement testbed

The testbed consists of an 80/20 housing, electronics box, and corer assembly. The testbed is portable, self-contained and is controlled over ethercat by multiple Beckhoff modules and Elmo Gold Whistle motor controllers. Commands are sent via a Dell Toughbook running the Casah2 software. The drill feed mechanism was designed and built to be flight-like, taking much of its design from the flight version. It is capable of pre-loading the bit up to 250 N (per flight), and has been tuned to operate with the same control bandwidth as expected in flight



Methodology

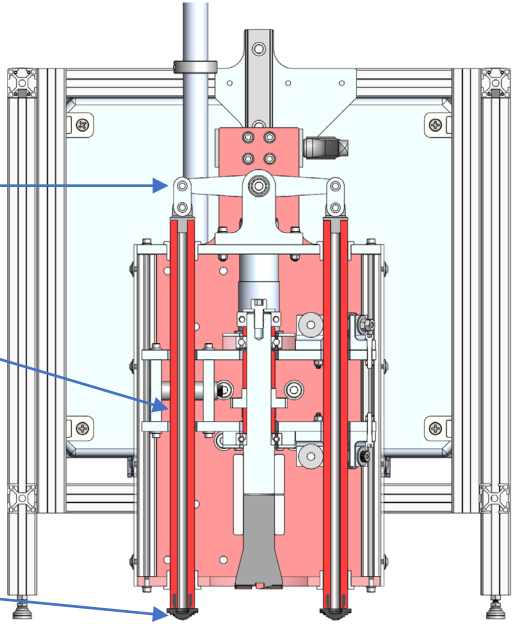
a) Formulation, theory or experiment description

- Abrading bit portable testbed continued
  - Testbed mimics flight system, using COTS components

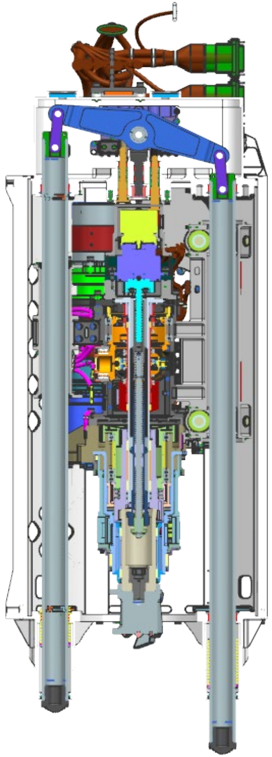
“Railizer” linkage

“Railizer” geometry matches flight system

3D Printed Stabilizer feet



testbed

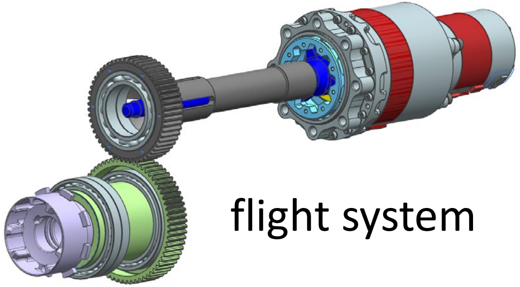


flight system

Methodology

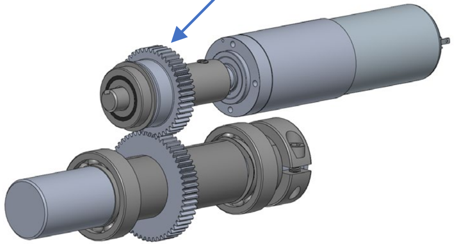
a) Formulation, theory or experiment description

- Abrading bit portable testbed continued



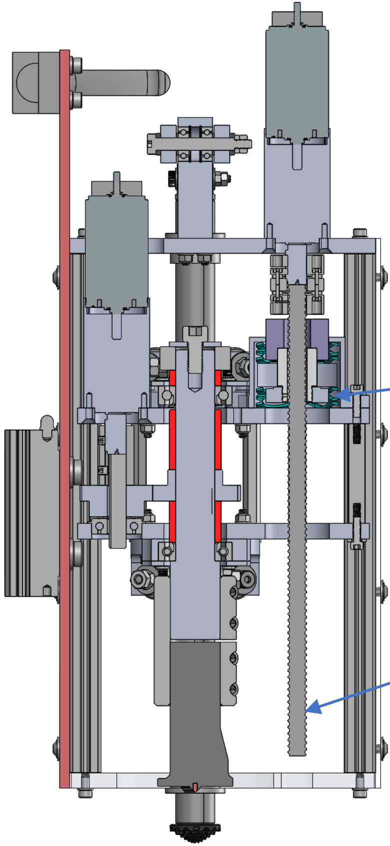
flight system

Gear ratios mimic flight system



testbed

No coring bit or bit exchange mechanism, abrading bit fixed directly to drill axis



Load cell supported using same flight system wavesprings

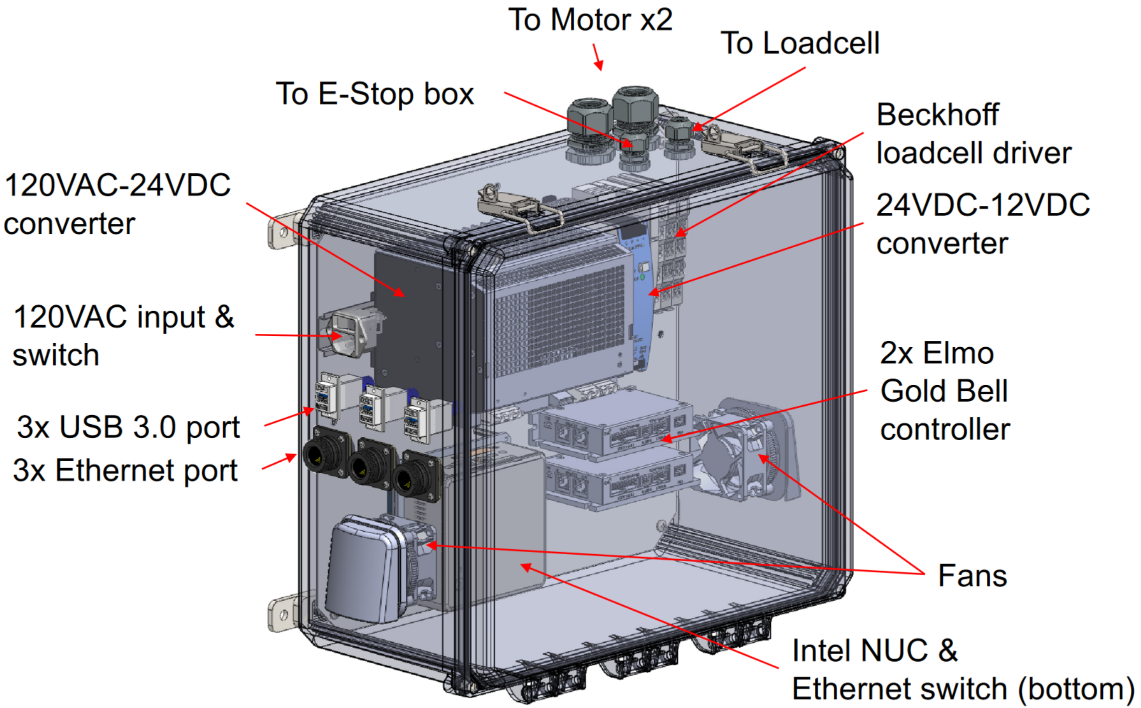
Ball screw feed mechanism with same pitch as flight system

testbed

Methodology

a) Formulation, theory or experiment description

- Abrading bit portable testbed continued
  - Degraded capability of the flightsystem compared to COTS components are represented including current measurement resolution, accuracy, and control bandwidths



electronics enclosure

Methodology

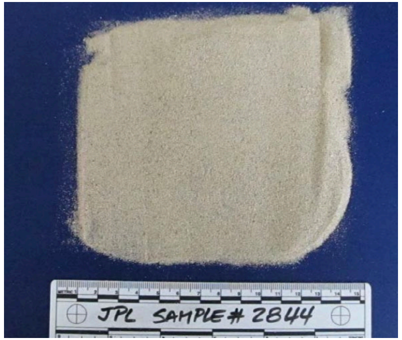
a) Formulation, theory or experiment description

- Simulants

To ascertain the accuracy with which the abrading bit is able to determine the strength properties of granular media, tests have been performed on four materials: Mojave Mars Simulant (MMS) Dust, Quartz sand, #90 M2020 mobility simulant, and JCS-1A Lunar simulant. Each of the materials was sent to a third party vendor, Cal Test Inspection, for characterization using equipment conforming to Direct Shear ASTM standards. The purpose of this testing was to establish baseline strength characteristics against which measurements using the abrading bit can be referenced.

MMS Dust

Quartz sand



#90 M2020 mobility simulant

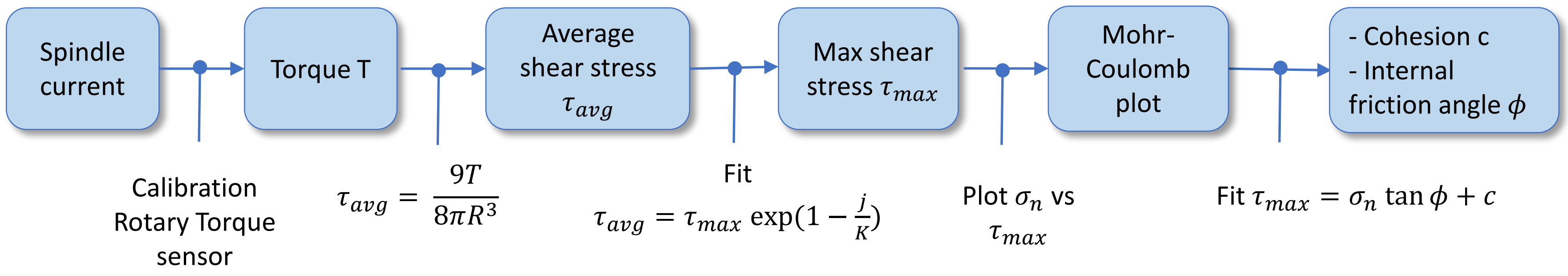
JSC-1A Lunar simulant

Methodology

b) Innovation, advancement

To acquire the motor telemetry and sensor data, CASAH2 framework is used. The weight-on-bit is measured by a load cell that was calibrated using an uniaxial force gage. To estimate accurate output torque at the abrading bit, spindle current versus torque calibration was conducted using a Futek rotary torque sensor (FSH02563).

Data processing approach for shear strength measurements



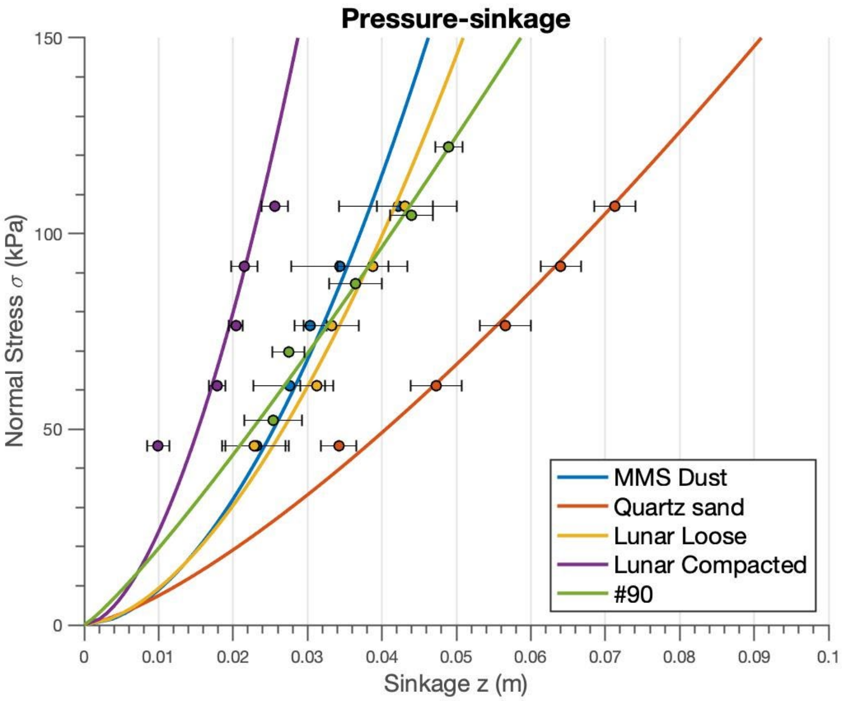
Results

a) Accomplishments versus goals

In this task, we quantified the accuracy and repeatability of measurements using the abrading bit. We performed tests on four material types and referenced them against results obtained using standard geotechnical equipment/standards (direct shear tests). Pressure-sinkage and shear strength measurements using the abrading bit are presented in the following slides.

Due to the Covid-19 mandatory telework, we were not able to take the four-wheeled RoboSimian robot out to Death Valley for field trials. As a result, we were not able to relate terrain strength measurements to vehicle performance and to use the statistical model developed in Y1 to determine if a statistical quantification of traversability is possible using this method.

Results – Pressure-sinkage

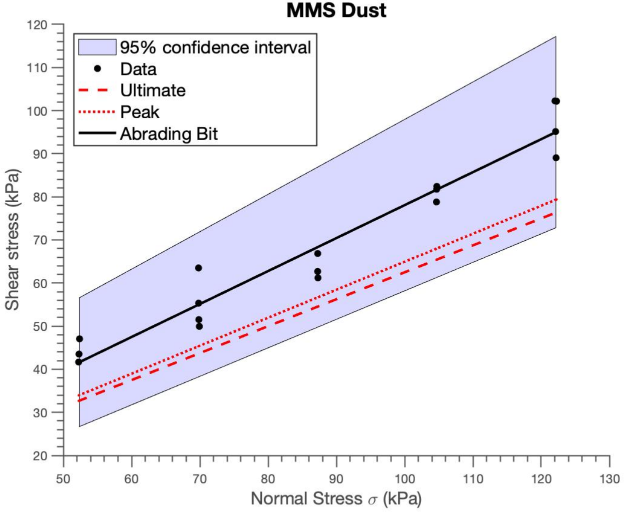


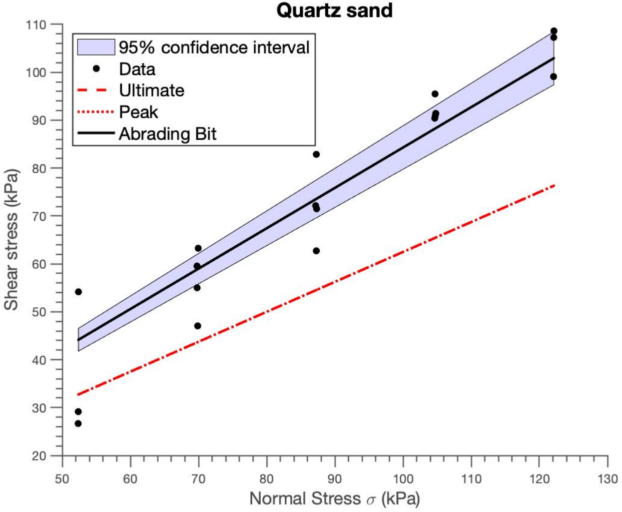
Pressure-sinkage relates to the bearing capacity of the soil and describes the relationship between the penetration depth z of the abrading bit into soil and the applied pressure p. A relationship between pressure and penetration depth is given by:

$$p = kz^n$$

	Soil deformation modulus k [N/m^{n+1}] (with 95% confidence bounds)	Soil deformation exponent n [-] (with 95% confidence bounds)
MMS Dust	$1.96e^{-5}$ [$-5.0e^{-5}$, $8.92e^{-5}$]	0.65 [0.34, 0.96]
Quartz sand	$1.47e^{-5}$ [$-2.60e^{-5}$, $5.53e^{-5}$]	0.72 [0.48, 0.97]
Lunar Loose	$4.02e^{-5}$ [$-9.05e^{-5}$, $17.1e^{-5}$]	0.59 [0.31, 0.88]
Lunar Compacted	$3.65e^{-5}$ [$-30.2e^{-5}$, $37.5e^{-5}$]	0.59 [-0.26, 1.37]
#90	$1.86e^{-6}$ [$-4.50e^{-6}$, $8.21e^{-6}$]	0.87 [0.57, 1.17]

Results – Shear strength measurements

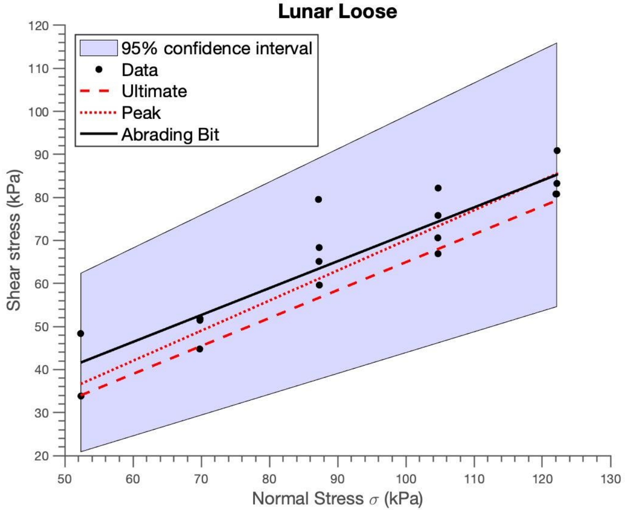


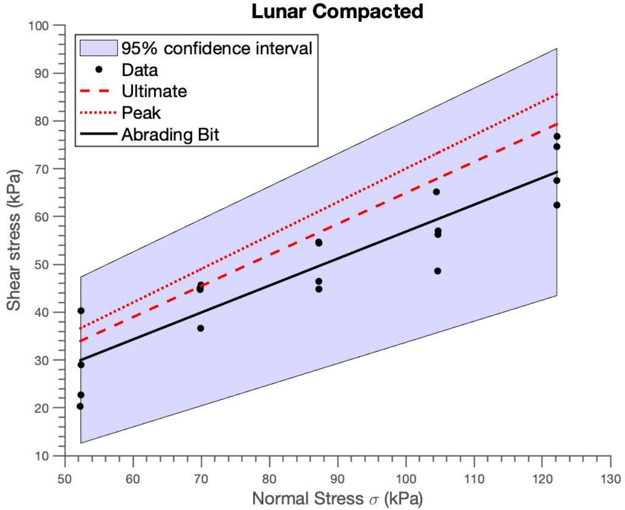


	Abrading bit	Direct Shear	
		Ultimate	Peak
Internal friction angle ϕ (deg)	43.8 [37.8, 49.3]	32	33
Cohesion c (kPa)	1.6 [0, 11.2]	2.0	1.4

	Abrading bit	Direct Shear	
		Ultimate	Peak
Internal friction angle ϕ (deg)	48.1 [45.8, 50.9]	32	N/A
Cohesion c (kPa)	0 [fixed at bound]	0	N/A

Results – Shear strength measurements

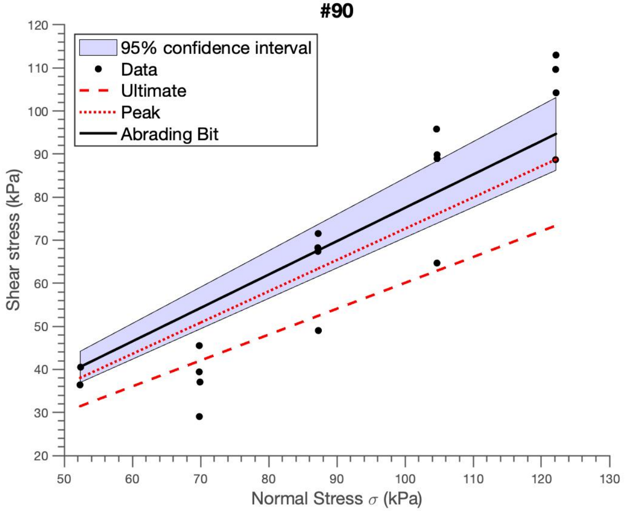




	Abrading bit	Direct Shear	
		Ultimate	Peak
Internal friction angle ϕ (deg)	35.8 [27.5, 43.9]	33	35
Cohesion c (kPa)	8.9 [0, 22.2]	2.8	4.8

	Abrading bit	Direct Shear	
		Ultimate	Peak
Internal friction angle ϕ (deg)	32.3 [25.2, 39.0]	33	35
Cohesion c (kPa)	8.9 [0, 11.5]	2.8	4.8

Results – Shear strength measurements



	Abrading bit	Direct Shear	
		Ultimate	Peak
Internal friction angle ϕ (deg)	44.4 [40.1, 48.1]	31	36
Cohesion c (kPa)	0 [fixed at bound]	3.4	6.9

Results

b) Significance

It was demonstrated that the M2020 Abrading Bit can be used as a geotechnical tool to measure standard soil strength properties utilized by the Terramechanics community to model and estimate vehicle traverse performance. If the Abrading Bit were to be used in flight this would….

- Enable in situ assessments of mobility and go-no-go decisions for M2020 operations

Accurate predictions of mobility performance have been, and presently remain, infeasible; the requisite terrain-strength properties have never been measured. Through the in situ measurement of terrain properties pertinent to mobility predictions, JPL would produce a first-of-its-kind dataset relating terrain-mechanical properties to observed rover performance.

- Enable the first high fidelity Mars regolith analogue to be produced based off in situ geotechnical measurments

The results of this study, if infused into flight, would represent the first quantitative and systematically obtained characterization of Martian regolith strength. At present, multiple unverified Mars analogues exist and vary significantly between institutions. Such analogues are frequently chosen either for their color or qualitative similarity to observations. Through the collection and sharing of quantitative results, JPL and its strategic partners will be better positioned to evaluate future concepts against a common

Results

b) Significance

- Inform the design of the Fetch Rover mobility subsystem and other future systems

As a smaller, four or six wheeled vehicle, the Fetch Rover must be capable of traversing terrains encountered by its larger, M2020 predecessor. On Earth, vehicle designers at TARDEC, ERDC, and elsewhere benefit from a priori knowledge of their target terrains gained by field engineers with specialized apparatus known as a Bevameter: a circular, toothed disk designed to touch the surface with a known preload, rotate, and collect surface shear and bearing strength data for mobility analyses. The results of Bevameter measurements are used to optimize wheel number, compliance, diameter, width, and grouser (tread) patterns for tractive efficiency. By developing the methodology by which the Abrading Bit can replicate Bevameter measurements, this task enables M2020 to take measurements that hold significant potential to inform the design and performance of the Fetch Rover.

c) Next steps

Engage Mars 2020 science team and Mars Campaign Office for demonstration on the rover Vehicle System Test Bed (VSTB) for flight like ops, data collection, and hardware.

References

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[3] H. A. Oravec, Understanding mechanical behavior of lunar soils for the study of vehicle mobility, PhD Thesis, 2009